

# Guest Editorial: Brain/Neuronal–Computer Game Interfaces and Interaction

## I. BRAIN–COMPUTER GAMES INTERACTION

**T**HERE have been many attempts to define the word “game.” The essential elements of a good game are play, nontrivial goals/challenges and rules, and games often involve a pretended or virtual reality. Nontrivial gameplay requires a challenge, but not so much of a challenge that the player becomes disinterested. Games, in general, have been around since ancient times to entertain us. Since the first electronic and video games appeared in the 1940s and 1950s, there has been an increasing demand for enhancements to existing games and new ways of interacting with computer games. More recently, games have been used to engage and stimulate us cognitively, to help us learn, and to help us recover from illness (e.g., edutainment and serious games). Buttons, mice, joysticks, joypads, and handheld devices have been the main human interfaces with games for many years, then came steering wheels, gear sticks, electronic musical instruments, and all sorts of peripherals that represent real-life objects. Today, brainwave- or electroencephalogram (EEG)-controlled game controllers add new options to satisfy the continual demand for new ways to interact with games, following trends such as the Nintendo® Wii, Microsoft® Kinect, and Playstation® Move, which are based on accelerometers and motion capture.

EEG-based game interactions are controlled through brain–computer interface (BCI) technology, which requires sophisticated signal processing to produce a relatively inaccurate and unstable control signal that provides a low communication bandwidth with only a few degrees of freedom. Extracting a reliable control signal from nonstationary brainwaves is a challenge being addressed by many researchers. Producing paradigms for training users to produce brain activity that is easily translated into a control is another key focus of BCI research. Another challenge is to develop games and game control strategies that can be operated using unstable and limited control signals to exploit the rich dynamics available in brainwaves. It is, therefore, important to engage those involved in game development to help develop new paradigms, not only for enabling nonmuscular game interaction but also for advancing the field of BCI in general.

Brainwave-controlled computer games have been researched since the 1990s, with an emphasis on using video games to improve the user’s performance in BCI experiments and to maintain motivation, as well as to modulate brain activity, with the aim of using that ability to interact with and control technology and to communicate, movement-free. More recently, entertainment and gaming have become a popular application focus for BCI researchers, and game developers have begun to engage in the challenge that such a field proposes. As a result, BCI games are becoming increasingly more advanced, incorporating 3-D environments, multiple user objectives, and hybrid control systems, including both conventional input devices and multiple BCI techniques.

Brain-controlled video games can be used to train users to intentionally modulate their brainwaves, to name just a few: 1) to enable communication for those with severe movement impairment; 2) to enable those who are physically impaired to enjoy video games; 3) for rehabilitation (e.g., poststroke rehab to encourage brain repair); and 4) for gamers, to augment and improve the game playing experience. The challenge is to train the users in paradigms that are moderately challenging (e.g., beyond simple cursor control), such that progressing from a training paradigm to a real-world communication/control situation significantly impacts the subject performance. Video games provide just such a learning environment, where increased cognitive load can be controlled by modulating the amount of stationary or moving objects/matter, which may or may not need to be attended to by the BCI user. Controllable distraction to the user can help the user learn to cope with such distractions when using BCI in the real world.

While, to date, there has been successful research into brain–computer game interaction (BCGI), the algorithms and techniques developed are limited in scope and may not utilize all available data in the appropriate contexts, e.g., optimizing for genre-specific games. While the importance of computer games, the challenge, and the competition provide key ingredients for motivating and engaging the users as they learn to control a BCI, it must be emphasized that brainwave-controlled games need to be developed to suit the end purpose or application. For entertainment, this is obvious: keep the users engaged, excited, challenged (but not too much), and immersed, where gamers must feel they are in control of the BCI. This may involve tailoring the difficulty to suit the players’ ability, which is acceptable for gaming when positive feedback is important, but may not be desirable for training when the end application requires precise and accurate selection, such as commands for assistive robotics or communication. For example, when a BCI is used as an alternative communication device, the objective is to maximize the probability of interpreting the user’s intent correctly. Therefore, the games should maintain a person’s motivation to perform better, try harder to produce the right brain activity and activate the correct area of brain, and provide feedback to the user to enable learning. However, if the BCI is aimed at inducing neuroplastic changes in specific cortical areas, i.e., in stroke rehabilitation (another application which involves games and BCI), the objective is not only to provide accurate feedback but also to encourage the user to activate regions of cortex or to produce oscillatory activities that do not necessarily provide optimal control signals in the context of BCI.

This special issue was, therefore, solicited to gain insights into new biosignal processing algorithms, tested in gaming applications, which exploit BCI and neural signals to enhance gameplay experience and player motivation, be the players able-bodied or physically impaired.

## II. THE PAPERS

In this special issue, a snapshot of the current trends in BCI-controlled computer games is presented across 11 manuscripts. Marshall *et al.* provide a review of the field to date, how it has grown over the past 20 years, and what types of BCI control strategies are suited to particular game genres, for the first time categorizing games used with BCIs into genres. The appropriateness of game genres (a category of games characterized by a particular set of gameplay challenges) and the associated gameplay challenges for different BCI paradigms are evaluated. Gameplay mechanics employed across a range of BCI games are reviewed and evaluated in terms of the BCI control strategy's suitability, considering the genre and gameplay mechanics employed. A number of recommendations for the field relating to genre-specific BCI-game development and assessing user performance are also provided for BCI-game developers. Interestingly, it was found that the action game genre was the most popular, even though action games tend to require fast responses, while motor imagery was the most used BCI approach for games, even though motor-imagery-based BCI normally requires training, which would be unusual for general gaming. The breadth of topics covered in this special issue correlate with the findings of the review by Marshall *et al.*, where motor imagery, steady-state visual evoked potentials (SSVEPs), and P300-based game interfaces are shown to be the most popular, with aspects of how biofeedback, user states, and emotions are also exploited to enhance gameplay.

Chumerin *et al.* evaluated the use of steady-state visual evoked potentials in a maze game on a consumer grade EEG device (the Emotiv EPOC) and a traditional EEG cap. The game was then tested using the consumer grade headset with a broad audience (53 persons) in a real-world setting. Most players enjoyed the game and had good control over it, yet a percentage of players found the stimuli difficult to concentrate upon. Recommendations for the BCI-game design, the fitting of consumer grade EEG headsets on participants, and the use of SSVEP stimuli in games are presented, based on the findings from the study.

Legeny *et al.* examine a context-dependent approach for an SSVEP-based BCI-game controller. The controller uses two kinds of behavior alteration. Commands may be added and removed if their use is irrelevant to the context or the actions resulting from their activation, and may be weighted depending on the likeliness of the actual users' intention. The controller was integrated in a test spaceship shooting game for a pilot study using 12 subjects. Preliminary results obtained confirmed the possible benefits in terms of a context-dependent controller, workload reduction, and performance improvement.

Leeb *et al.* describe a multimodal approach using an asynchronous BCI in parallel with a manual joystick control signal, while playing a game in virtual reality. The subject controls a penguin character sliding down a mountain slope, in which steering the game character left or right was achieved with a joystick, whereas making the character jump was achieved using foot motor imagery. The BCI was built upon the so-called brain switch, which allowed for discrete and asynchronous actions. Results from 14 subjects showed that the use of a secondary motor task (in this case, joystick control) did not deteriorate the

BCI performance during the game. These findings show that BCI may be used in a multimodal or hybrid BCI implementation in which a user can perform two tasks in parallel. These are encouraging results, suggesting that BCI can indeed be used as an additional control in computer games.

Thurlings *et al.* studied a different aspect of multitasking, in particular, dual-attentional tasks for event-related potential (ERP)-based BCI, investigating if and to what extent ERPs and ERP-BCI performance are affected in a dual-task situation and if these effects are a function of the level of difficulty of a concurrent task. These two tasks consist in attending to tactile stimuli (for ERP-based BCI control) and performing a visual memory task. The study showed that when users are required to perform these two tasks simultaneously, the resulting ERP-based BCI performances drop significantly. While they are still higher than chance, they become lower than what would be necessary for effective control.

Overall, the studies on multitasking may suggest that using spontaneous BCI, such as motor-imagery-based BCI, can be used in addition to other motor control commands (e.g., a joystick), but that ERP-based BCI may not be used in addition to other attentional tasks, hence constraining the types of games in which ERP-based BCI can be used.

A more specific look at BCI games was provided by Kaplan *et al.* in a review of BCI-controlled games, based on the P300 evoked potential. The shortcomings of the P300 BCI in gaming applications are reviewed, and it is outlined how solutions for overcoming these shortcomings already exist in several different games. Problems such as static stereotyped stimuli, goal selection control instead of process control, repeated stereotyped mental actions required to control a single action in the game, and the synchronous protocols associated with P300 are reviewed. Solutions for these problems are found in existing BCI games, as well as recommendations for making future P300 BCI games more practical.

Kos'myna and Tarpin-Bernard present an evaluation of a multimodal combination of BCI paradigms and eye tracking with consumer grade hardware in a game. The paper evaluates three combinations of BCI and eye tracking, used in the context of a simple puzzle game. The SSVEP, motor imagery, and eye tracking are used in several different combinations to identify the extent to which the paradigms impact the playability of the game. The paper presents preliminary results that indicate that BCI interaction is tiring and imprecise, yet may be suited as an optional and complementary modality to other interaction techniques. The combination of the eye tracker and SSVEP was found to be the most well-rounded and natural combination.

In terms of practical focus for BCGI, Scherer *et al.* propose the use of games to enhance the user experience when collecting behavioral data for research. The rationale is that experimental paradigms used to collect behavioral trials from individuals are data centered and not user centered, resulting in the experimental paradigms that are generally demanding for the user/participant, and not always motivating or engaging. An approach involving the use of the Kinect motion tracking sensor in a game-based paradigm for noninvasive EEG-based functional motor mapping is proposed to alleviate this problem by making the data collection experience more interesting to the user. Results from an experimental study with able-bodied participants

playing a virtual ball game suggest that the Kinect sensor is useful for isolating specific movements during the interaction with the game, and that the computed EEG patterns for hand and feet movements are in agreement with results described in the literature.

Berta *et al.* provide an EEG and physiological signal analysis for assessing flow in games. The paper defines flow in games as a measure of keeping the player fully immersed and engaged in the process of activity within the game. The evaluation of flow involves a four-electrode EEG, using the low beta frequency bands for discriminating among gaming conditions. Using simple signals from the peripheral nervous system, three levels of user states were branded using a support vector machine classifier. The user states were identified, using three levels of a simple plane battle game, identifying states of boredom, flow, and anxiety. The paper argues that a personalized system could be implemented in a consumer context, allowing for more flowing gameplay in consumer games.

Van de Laar *et al.* investigate whether the incorporation of BCI into the popular game *World of Warcraft* affects the user experience. A BCI control channel based on alpha band power is used to control the shape and function of the avatar in the game. The character within *AlphaWoW* has two forms: an elf and a bear. The elf form allows them to attack enemies from a safe range and the bear form allows them to attack from close range (the bear is also more resistant to attacks). The “shape shifting” in the game is controlled via the user’s parietal alpha activity. This study suggests that the use of BCI control can be as much fun and natural to use as conventional controls, even if the player’s control is limited.

Finally, in the paper by Bonnet *et al.*, we see a first step toward multibrain games, that is, games where two (or more) players compete or collaborate to steer a ball in the direction of goalposts left and right on the screen. Steering is done using motor imagery. In the collaborative version, players make a joint effort to steer the ball in the same direction. In the competitive version, their efforts are compared, and the ball goes in the direction of the goalposts indicated by the strongest motor imagery control. The paper makes clear that multibrain control of a BCI game is possible and enjoyable for the players.

### III. DISCUSSION/CONCLUSION

In recent years, many proof-of-concept investigations have shown that BCI can be used to control computers, therefore they can be used in computer games. This special issue presents a variety of examples representing the latest developments in BCI-based game designs and outlines progress in the field, including designs and studies of more complex and more practical BCI-based games, beyond simple proof-of-concept investigations. The papers presented in this special issue have attempted to study issues related to multitasking with BCI control, multi-player BCI gaming, BCI-game design constraints, natural and efficient integration of the BCI system and its limitations in the game, use of commercial EEG devices, bio/neurofeedback for adaptive/passive gaming, BCI-game performance assessment, and BCIs and BCI game categorization by genre and suitability to genre design, among other interesting aspects that, together, render this special issue special.

The progress outlined herein will no doubt increase the interest in BCGI and make BCI-based gaming a mainstream technology of the future. This technology will offer not only entertainment but will also enhance many of the applications that are linked with BCI and may provide assistive enabling technologies to the physically impaired, as well as provide interesting and challenging activities enabling users to learn how to modulate brain activity more proficiently. Naturally, there are still a number of research problems that need to be solved to increase the market penetration of BCI games. These include: completely suppressing BCI calibration or camouflaging it in the game design and story, as well as identifying the kind of BCI controls that are the most efficient in a gaming context and/or the most enjoyable for the players. This also includes finding seamless ways to train players during the course of the game. As Marshall *et al.* suggested, to learn how to best tackle such challenges, as BCI games evolve and further studies are conducted, it will be important for all investigators to consider and report the many different variables that dictate performance. For example, the player’s level of BCI control proficiency (measured as game performance and as BCI performance), the number of sessions a user has undertaken, types of control strategies, BCI setup, including the number of electrodes used, types of assistance within the game and game AI, and game distractions and environments, along with other variables, should be reported consistently. This will allow assessment of progress in the field on an ongoing basis and the development of a clearer picture of the best practices and best designs for BCGI. There are exciting research problems ahead that BCI-based game designers will have to address, affording researchers fun with computer games while serious and beneficial research is being conducted.

DAMIEN COYLE, *Guest Editor*  
Intelligent Systems Research Centre  
Faculty of Computing and Engineering  
University of Ulster  
Londonderry, BT48 7JL, U.K.  
dh.coyle@ulster.ac.uk

JOSE PRINCIPE, *Guest Editor*  
Computational NeuroEngineering Laboratory  
Department of Electrical & Computer Engineering  
University of Florida  
Gainesville, FL 32611-6130 USA  
principe@cnel.ufl.edu

FABIEN LOTTE, *Guest Editor*  
Inria Bordeaux Sud-Ouest  
LaBRI Potioc  
Talence Cedex, 33405 France  
fabien.lotte@inria.fr

ANTON NIJHOLT, *Guest Editor*  
Universiteit Twente  
Enschede, 7500AE The Netherlands  
A.Nijholt@utwente.nl

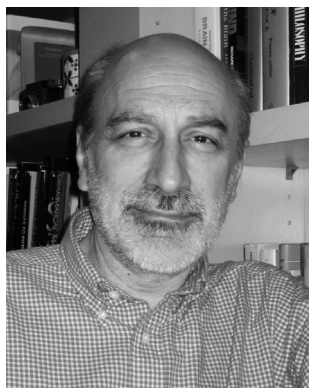


**Damien Coyle** (S'04–M'05–SM'12) received a first class degree in computing and electronic engineering and the Ph.D. degree in intelligent systems engineering from the University of Ulster, Londonderry, U.K., in 2002 and 2006, respectively.

Since 2006, he has been a Lecturer/Senior Lecturer at the School of Computing and Intelligent Systems and a member of the Intelligent Systems Research Centre, University of Ulster, where he is a founding member of the Brain–Computer Interface (BCI) Team and the Computational Neuroscience Research Team (CNRT). His research interests include brain–computer interfaces, computational intelligence, computational neuroscience, neuroimaging, and biomedical signal processing. He has coauthored several journal articles and book chapters in these areas.

Dr. Coyle is the 2008 recipient of the IEEE Computational Intelligence Society's Outstanding Doctoral Dissertation Award and the 2011 recipient of the International Neural Network Society's Young Investigator of the Year Award. He received the University of Ulster's Distinguished Research Fellowship award in 2011 and the Royal Academy of Engineering/The Leverhulme Trust

Senior Research Fellowship in 2013. He is an active volunteer in the IEEE Computational Intelligence Society.



**Jose Principe** (M'83–SM'90–F'00) received the Engenheiro degree from the University of Porto, Porto, Portugal, in 1972, and the M.Sc. and Ph.D. degrees in electrical engineering from the University of Florida, Gainesville, FL, USA, in 1975 and 1979, respectively. He holds Honoris Causa degrees from the Universita Mediterranea, Reggio Calabria, Italy; Universidade do Maranhao, Maranhao, Brazil; and Aalto University, Espoo, Finland.

He has been a Distinguished Professor of electrical and biomedical engineering with the University of Florida since 2002. He is BellSouth Professor and Founding Director of the University of Florida Computational Neuro-Engineering Laboratory (CNEL). He joined the University of Florida in 1987, after an eight-year appointment as Professor with the University of Aveiro, Aveiro, Portugal. He chaired 78 Ph.D. and 61 Master student committees, and he is author of more than 600 refereed publications (5 books, 7 edited books, 19 book chapters, 201 journal papers, and 427 conference proceedings). He holds 22 patents and has submitted seven more.

Dr. Principe has been a Fellow of the AIMBE since 2006, and the IAMBE since 2012. He served as President of the International Neural Network Society in 2004, as Editor-in-Chief of the *IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING* from 2001 to 2007, and as a member of the Advisory Science Board of the FDA from 2001 to 2004. He is currently the Founding Editor in Chief of the *IEEE Reviews in Biomedical Engineering*. He has been heavily involved in conference organization and several IEEE society administrative committees. He is a recipient of the INNS Gabor Award, the IEEE Engineering in Medicine and Biology Society Career Achievement Award, and the IEEE Computational Intelligence Society Neural Network Pioneer Award.



**Fabien Lotte** received the M.Sc. and M.Eng. degrees and Ph.D. degree in computer sciences from the National Institute of Applied Sciences (INSA), Rennes, France, in 2005 and 2008 respectively.

As a Ph.D. candidate, he was a member of the BUNRAKU team at the Inria Rennes Bretagne-Atlantique and a member of the OpenViBE project dedicated to brain–computer interfaces and virtual reality. He was supervised by Dr. A. Lecuyer and Pr. B. Arnaldi. In 2009 and 2010, he was a Research Fellow at the Institute for Infocomm Research (I2R), Singapore, working in the Brain-Computer Interface Laboratory, led by Dr. C. Guan. Since January 2011, he has been a Research Scientist (with tenure) at Inria Bordeaux Sud-Ouest, Talence Cedex, France, in the Potioc team. His research interests include brain–computer interfaces, virtual reality and 3-D interaction, pattern recognition, and signal processing.

Dr. Lotte received both the Ph.D. dissertation award in 2009 from the French Association for Pattern Recognition (AFRIF) and the Ph.D. dissertation award in 2009 (second prize) from the French Association for Information Sciences and Technologies (ASTI).



**Anton Nijholt** studied mathematics and computer science at the Technical University of Delft, Delft, The Netherlands and received the Ph.D. degree in theoretical computer science from the Vrije Universiteit, Amsterdam, The Netherlands, in 1980.

He is a Professor of Computer Science in the Human Media Interaction group, University of Twente, Enschede, The Netherlands. He held positions at various universities in and outside The Netherlands. His main research interests are entertainment computing, multimodal interaction, affective computing, and brain–computer interfacing. He has hundreds of scientific publications, including (edited) books on the history of computing, language processing, and brain–computer interfacing. In preparation are books on “playful interaction” and “entertainment for the whole world.”

Prof. Nijholt has served as Program Chair and General Chair for conferences on affective computing and entertainment computing and has been Guest Editor for various journals.